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REVERSIBLE METAL HYDRIDE-AIR FUEL CELL

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) A 60 watt portable power fuel cell system has been built operating on ambient air and hydrogen as supplied by the deactivation of lanthanum nickel hydride. The use of the endothermic hydride deactivation process in conjunction with the fuel cell considerably reduced steady state system operating temperatures. The hydride reaction was initially sustained through use of heating coil, but thereafter could be maintained at 20°C by transferring waste heat from the fuel cell.		

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This is the final technical report for Contract No. DAAB07-77-C-2644 covering the work performed between February, 1977 and February, 1978. The objective of this program entitled 60 Watt Reversible Metal Hydride Fuel Cell System was to develop a highly efficient, lightweight, easily refuelable, silent power generating system for use with military communication equipment.

During a previous program at ERC, Contract No. DAAB07-72-C-0317 entitled Metal Hydride - Air Battery, the conceptual feasibility of a portable fuel cell system had been demonstrated.¹ An operational life of 550 hours was obtained for a system delivering 28 VDC at a rated power of 30 watts. The system consisted of three main subsystems; an alkaline fuel cell stack operating on hydrogen and ambient air, a fuel generator producing hydrogen by the aqueous decomposition of sodium aluminum hydride, and a DC to DC power conditioning unit which converts the fuel cell power to a regulated constant output. Attempts to double power density by increasing the net system output to 60 watts within the same volume configuration presented a more complex challenge. The doubling of the power requirement inherently nearly doubled the heat producing capability of the fuel cell stack. This coupled with the increased heat produced by the hydrogen generator resulted in much higher steady state system temperatures. Although the fuel cell could tolerate these higher temperatures to a degree, eventually a bubbling phenomenon was introduced within the cells. At this point, direct recombination of cell reactants was believed to be occurring, thus leading to possible thermal runaway conditions. Attempts to retard overheating of the 60 watt system through use of improved electrodes, heat transfer fins and blowers were only marginally successful.

This contract represents an effort to improve upon the operating characteristics of the 60 watt power generating system by means of reducing the net heat produced by the components during operation. The fuel cell and power conditioning units essentially remained the same as in previous programs, but a significant change was made in the technique for generating hydrogen to operate the fuel cell. The change involved replacing the exothermic sodium aluminum hydride reactor with a reversible metal hydride storage unit which absorbs heat upon the release of hydrogen. It was initially estimated that total heat output of the system could be reduced by about 65 percent utilizing the endothermic hydrogen generating concept. The metal hydride selected for evaluation for this system was lanthanum nickel hydride.

The preliminary design for the 60 watt, reversible metal hydride, fuel cell system was governed by the technical guidelines for the contract. The guidelines specified that the unit should have a rated power output of 60 watts, an output voltage of 28 VDC

+ 5 percent, an operational ambient temperature of -18°C to 38°C , a total weight of not greater than 18 pounds based upon an operation time of four hours, and an energy density of at least 70 watt hours per pound based upon the weight of the filled hydride container. The system was to be able to mate with other military equipment, thus its footprint was restricted to a $3\frac{1}{2}$ " by 12" area. In addition, the unit was to function dead-ended during normal operation thus all fuel would be consumed in the fuel cell.

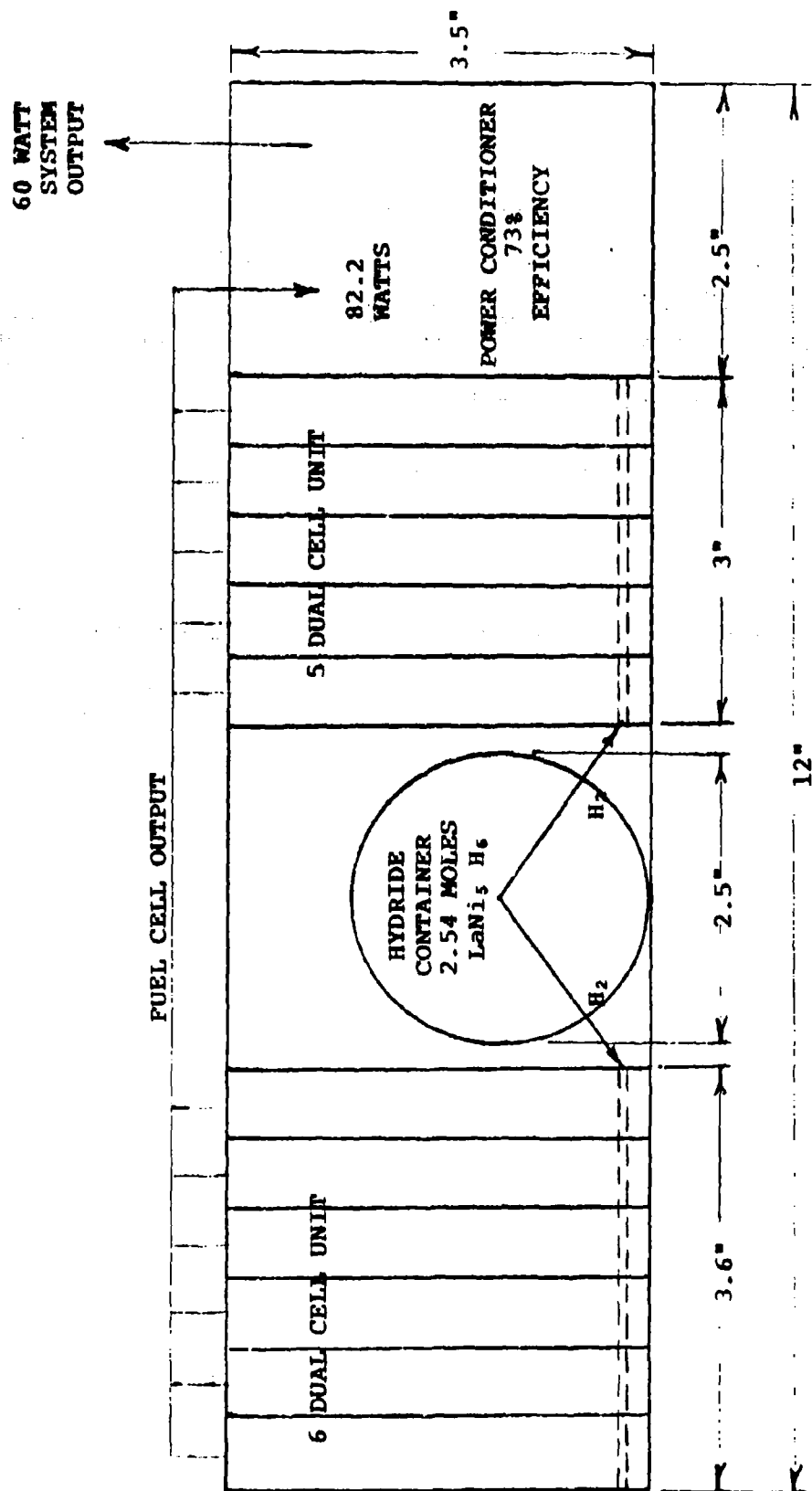
The technology available at the outset of this contract concerning the power conditioning unit was limited to that previously obtained under Contract DAAB-07-72-C-0317. This automatically did set certain efficiency ratings to the unit. The design of the hydride storage unit was controlled mainly by the amount of hydrogen necessary to operate the fuel cell for the specified time. Its size would also be limited by the space available within the specified footprint.

Figure 1 shows a simplified schematic diagram of the system as visualized at the initiation of this contract. The power conditioning unit has been borrowed from the system delivered under Contract DAAB-07-72-C-0317 and therefore its width was fixed at $2\frac{1}{2}$ inches and efficiency at 73%. The fuel cell stack would therefore be required to operate at a power level of about 82.2 watts at rated system power. The stack selected consisted of 22 series connected cells. Two individual cells were packaged within a single cell housing and was referred to as a dual cell element. Previous experience with the fuel cell electrodes in this cell configuration indicated that an average cell voltage of 870 mv at 4.3 amperes could be expected during initial stack life in order to meet the power requirement. Cell decay would occur during normal operation due to various mechanisms including carbonate formation. Cell performance at end of life was estimated to be 800 mv at 4.65 amperes in order to maintain the power level.

Each cell within the stack occupied about .3 inches of the footprint width thus the total stack would be approximately $6\frac{5}{8}$ " wide. The maximum width of the hydride storage unit was therefore limited to $2\frac{7}{8}$ inches. A split fuel cell stack was selected both from the viewpoint of keeping the cells from heating excessively and also to aid in transferring heat to the hydride container which had a tendency to get very cold. The stack had to be split along dual cell elements, therefore one section contained 12 cells and the other contained 10 cells.

The hydride storage unit would be required to supply about 7.63 gram moles of hydrogen based upon end of life conditions. Since each mole of lanthanum nickel has the capability of storing approximately 3 moles of hydrogen, 2.54 moles or about 1100 grams of the metal was required. The activation and storage of the hydride was performed at moderate pressures, thus a pressure vessel was required. The design of the pressure vessel was based upon experience and tooling gained by ERC during previous aerospace hydrogen battery programs. The initial design was a 4 inch high, 2.5 inch

FIGURE 1 SIMPLIFIED SCHEMATIC OF 60 WATT SYSTEM



diameter cylinder which was subsequently shown to be undersized.

The basic operating principle governing this power source was that hydrogen is supplied to the fuel cell on demand. The demand results from the negative pressure created by hydrogen consumption within the dead-ended fuel cell. The output of the fuel cell stack is controlled electronically by the power conditioner regardless of stack voltage fluctuations. The logic behind the system operation breaks down only if heat can not be added to the hydride source at a rate sufficient to release the required amount of hydrogen from the hydride. This was the major systems concern at the initiation of this program.

3.0 SYSTEM COMPONENTS

3.1 Fuel Cell

The fuel cell portion of this system consisted of 22 KOH electrolyte cells operating on pure hydrogen supplied from the hydride container and ambient air as supplied by natural convection up through the stack. The active area of each cell was about 2.69 inches by 7.25 inches or .135 square feet. Each cell nominally gave an initial performance level of 870 mv at a current density of 31.8 ASF. Both anodes and cathodes were prepared identically and consisted of a platinum black catalyst layer, bonded together with PTFE which was mounted upon a nickel screen current collector. A porous PTFE film was placed upon the gas side of the electrode to prevent excessive weepage of the free alkaline electrolyte.

The cell electrodes were contained within an injection molded polysulfone frame. Each frame held two anodes and two cathodes and therefore was referred to as a dual cell unit. The two anodes within the frame shared a common hydrogen compartment which was .115 inches wide. A separator rib as shown in Figure 2 was molded within the frame to support the individual anodes. The electrolyte compartment between anode and cathode was .110 inches wide and contained a similar rib pattern which was separately molded. The outer .125 inches of each frame provided the air passage for each cathode. This passage doubled in width when mated with an adjacent dual cell. A corrugated PTFE coated nickel screen provided support for the cathodes in this area. The individual electrodes were bonded to the step portions of the frame with epoxy. Figure 3 shows the construction of a dual cell unit. Each electrode had a nickel tab welded to its current collector. The edge collection technique to connect all cells in series is shown in Figure 4.

In addition to the dual cell elements, the fuel cell subsystem also contained an electrolyte reservoir and a sump assembly. The electrolyte reservoir provided a volume for excess electrolyte so that expansion, contraction, evaporation and dilution processes would not reduce active electrode area. The reservoir, approximately 2 inches high, was above the individual cells and was separated into compartments. A .035" hole in the divider between compartments

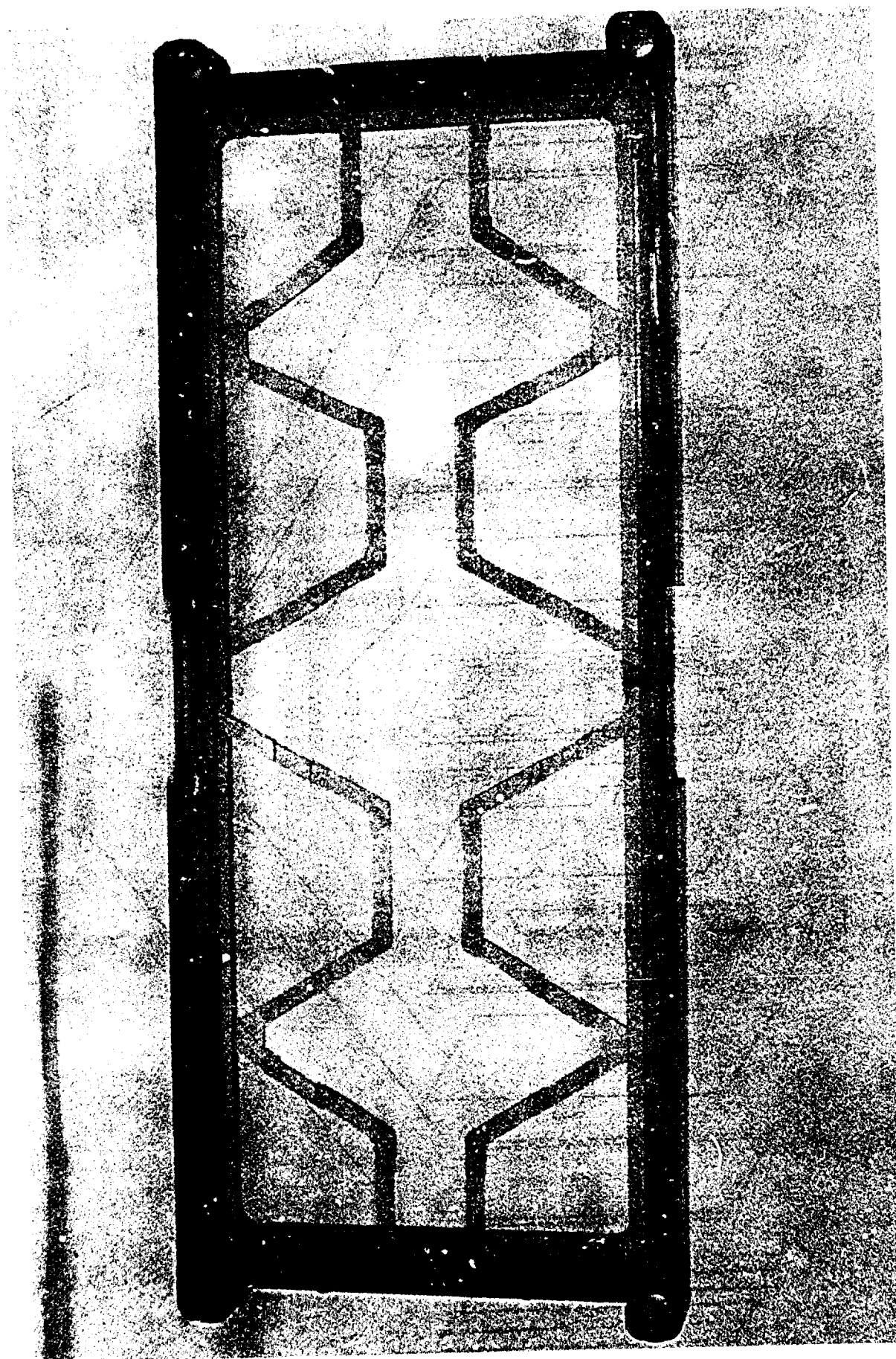


FIGURE 2 POLYSULFONE FRAME FOR DUAL CELL

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FIGURE 3 DUAL CELL UNIT ASSEMBLY

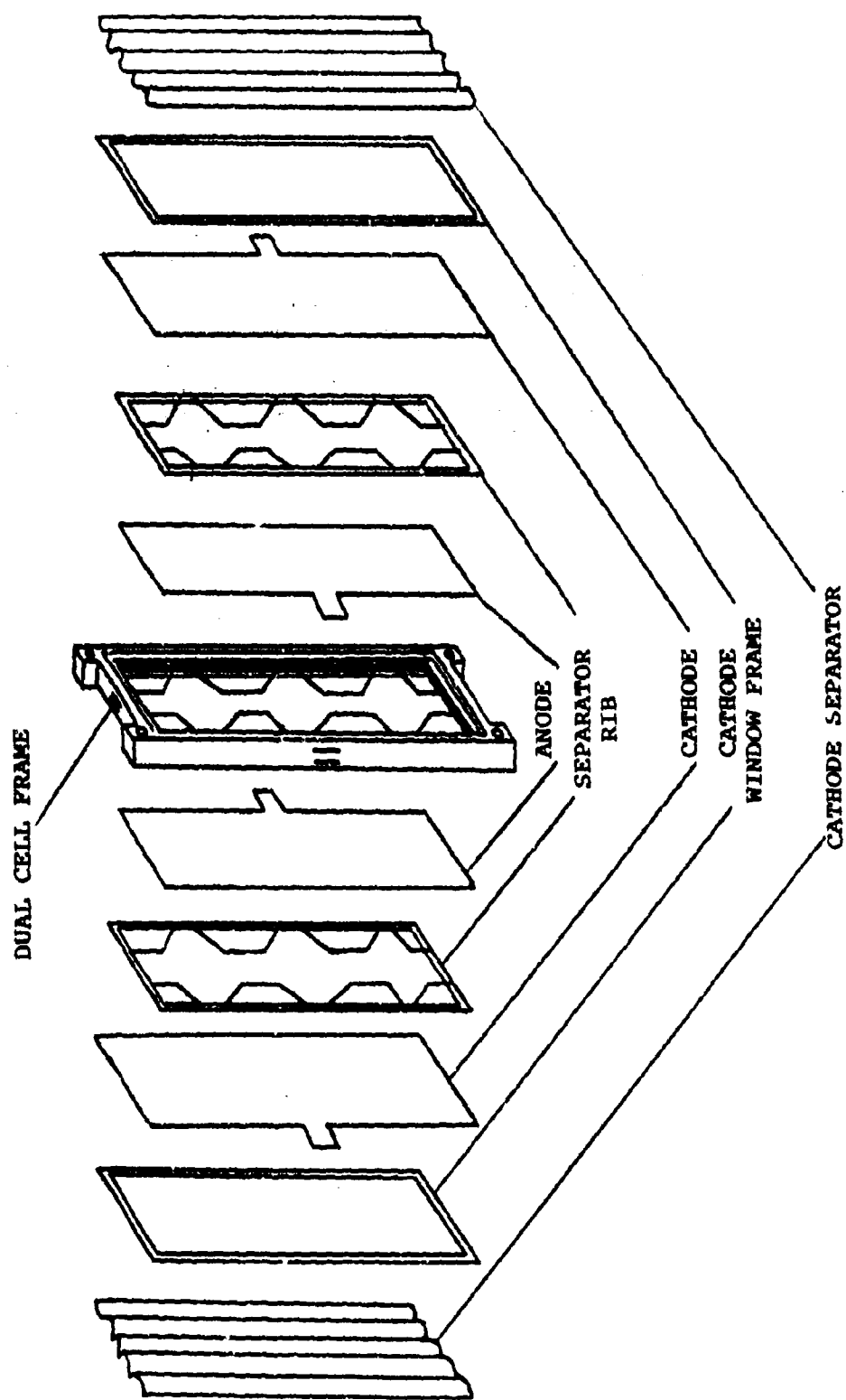
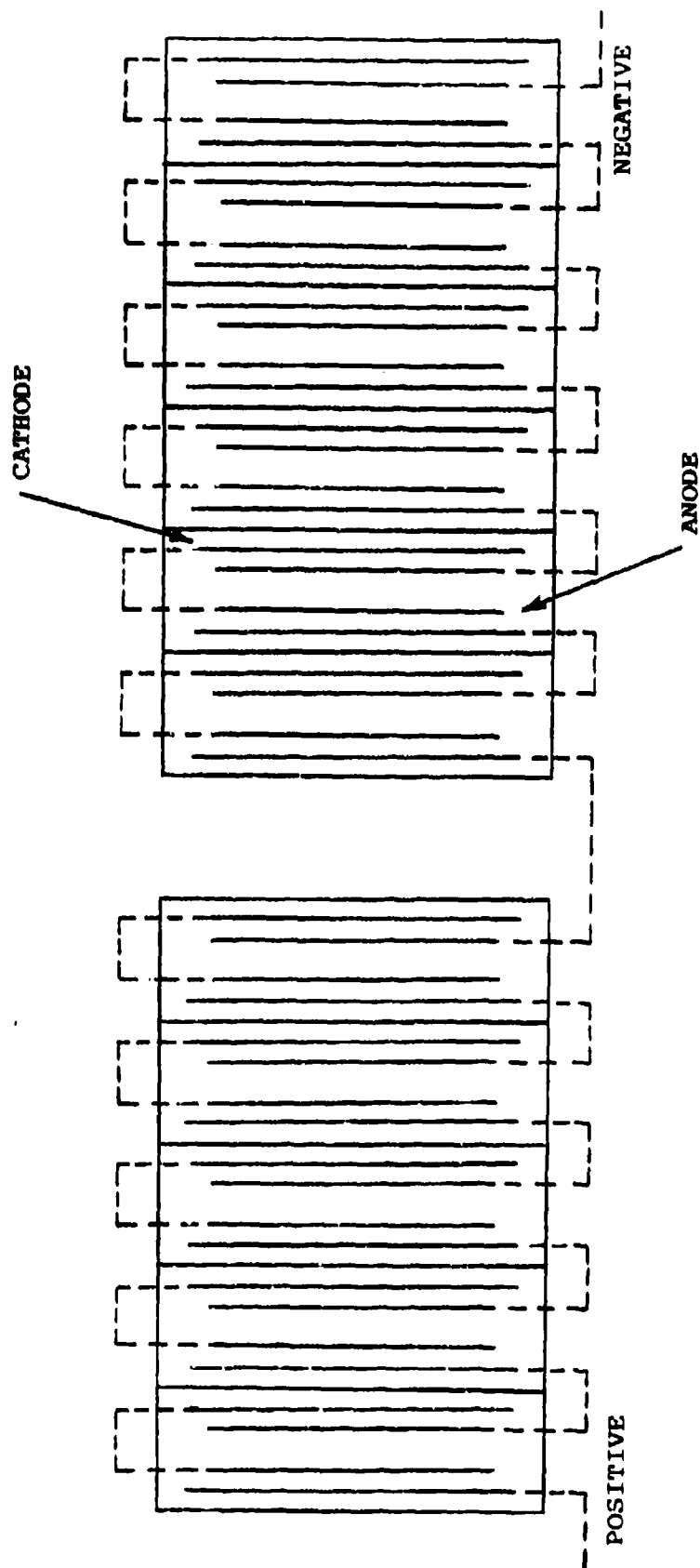


FIGURE 4 FUEL CELL STACK ELECTRODE CONNECTION



served to equalize the electrolyte levels in all cells. Electrical shorting through common electrolyte was believed to be minimized using this arrangement. In addition, both sides of the split fuel cell stack were interconnected by means of overflow tubes.

The primary function of the sump assembly unit was to collect electrolyte which weeped through the cell electrodes. The weepage was caused by carbonate formation within the electrodes which formed a path for loss of electrolyte from each individual cell. The electrolyte weepage from the anodes and cathodes were drained into separate chambers within the sump assembly, which were interconnected by ball valves. The liquid collected could be returned to the reservoir by means of a small pump built into the sump assembly.

The anode electrolyte chambers, one on both sides of the split stack, also served as the fuel exhaust ports during the purge operation cycle. Difficulties were encountered in consistently parallel purging both the 12 cell and 10 cell stack units together. A more reliable approach consisted of taking the 12 cell units' exhaust in the sump assembly and feeding it directly to the 10 cell unit. Figure 5 shows the positioning of the sump assembly to the fuel cell and the electrolyte reservoir. A forced air duct on top of the sump is also shown. The duct takes forced air provided by blowers built within the power conditioner to aid in removing product water. Figure 6 is a photograph of the complete fuel cell subsystem.

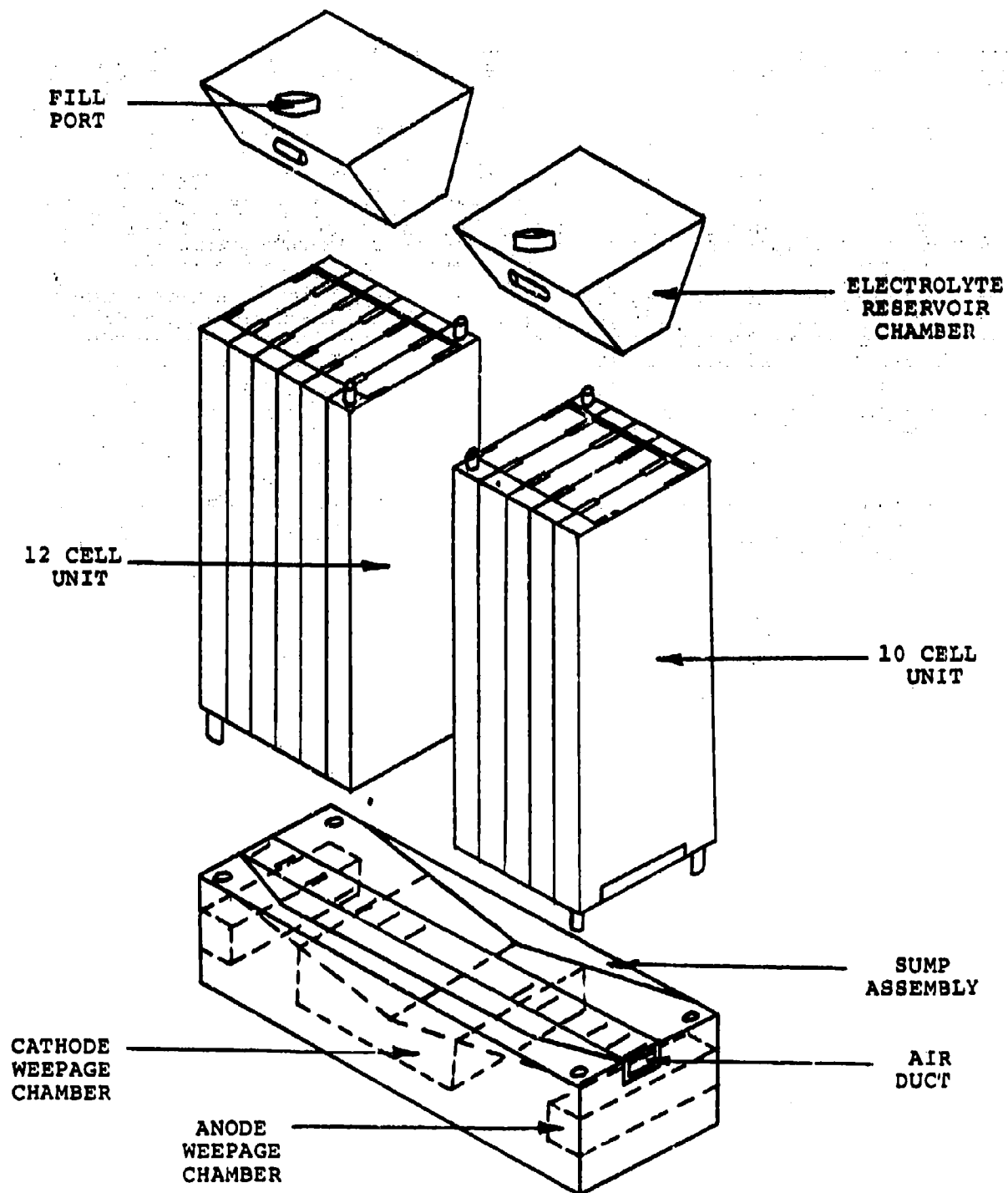
3.2 Hydride Storage Unit

The hydride storage unit served as the fuel supply to operate the fuel cell stack for the required period. The unit was based upon the principle that certain metals or alloys have the ability to take up large amounts of hydrogen gas within their crystal structure. This technique appears to be very attractive for some applications, since the weight of storable hydrogen can be twice that for an equivalent volume of liquified hydrogen.² Although technology in this area is relatively new, much research is presently being conducted.

Among the compounds that are being investigated are iron titanium, vanadium, magnesium nickel, lanthanum nickel, and various other rare-earth metal and nickel alloys. ERC had gained experience with these materials previously during a program to investigate hydrogen storage technique for use in conjunction with metal hydrogen batteries.³ Based upon past experience, lanthanum nickel appeared to be the best choice for a hydride material for this contract because of the relative ease of activating and deactivating.

The activation reaction for lanthanum nickel is approximately

FIGURE 5 FUEL CELL ASSEMBLY



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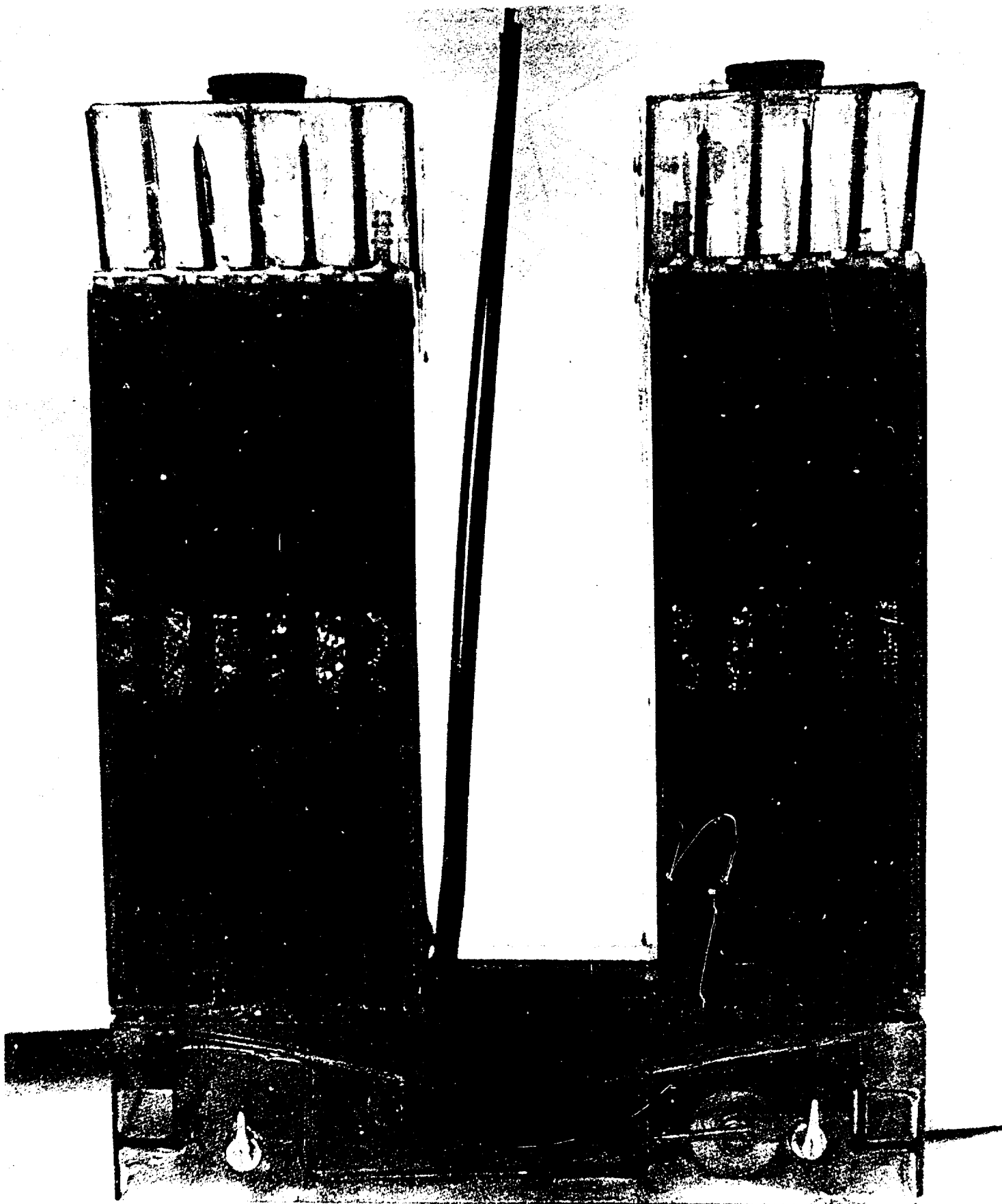
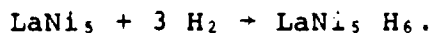


FIGURE 6 FUEL CELL SUBSYSTEM

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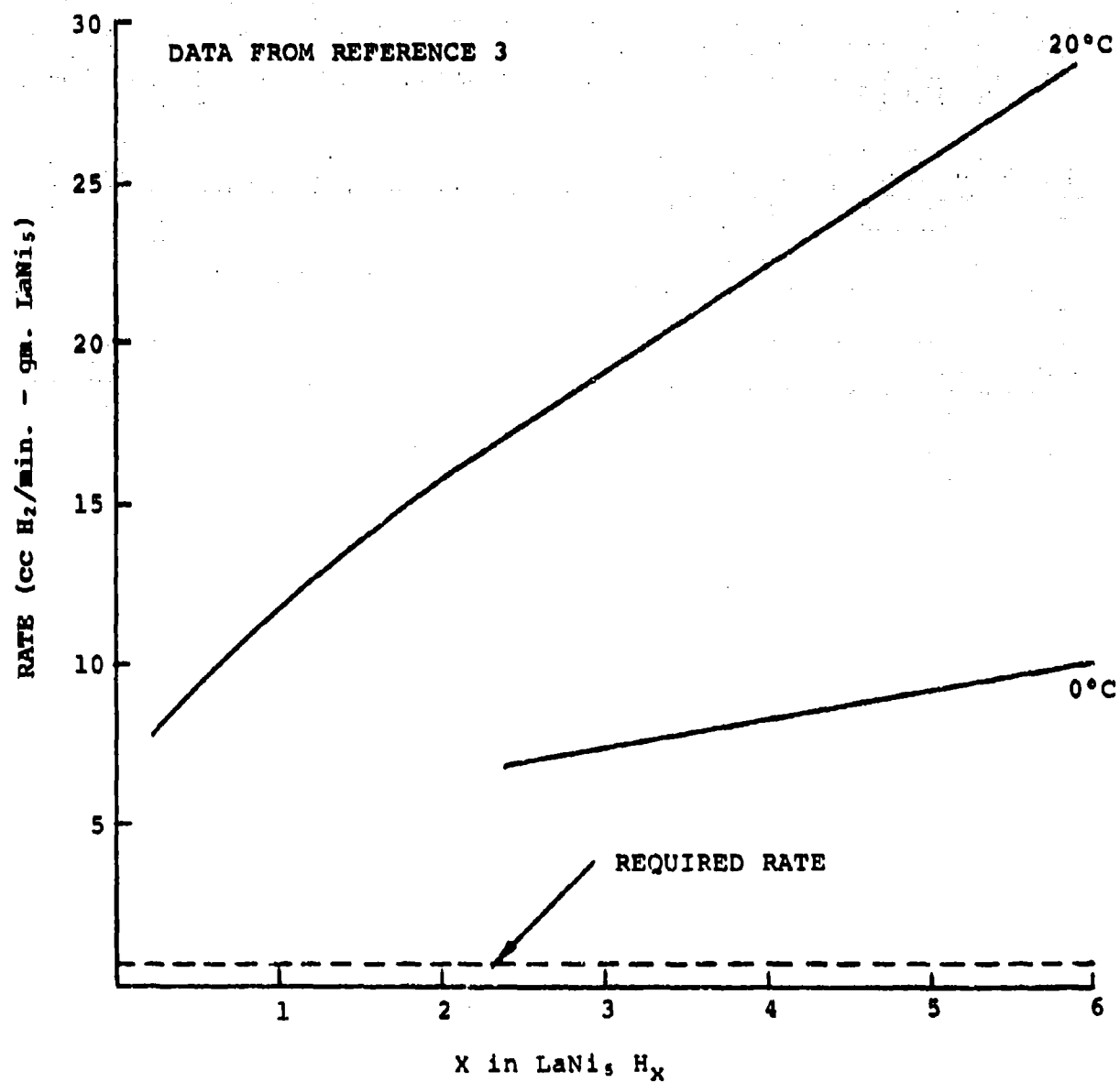
Approximately 7.2 kcal per mole H_2 is given off during the activation procedure. Conversely the deactivation process requires 7.2 kcal per mole H_2 liberated from the hydride. Hydrogen absorption and desorption does depend on both temperature and pressure. Typically, at constant temperature, most of the desorption does occur within a small pressure range. This is approximately 30 psi at ambient temperature with lanthanum nickel hydride. Data has been compiled by various investigators of the equilibrium pressure plateau at various temperatures.''' At 0°C the plateau for the isothermal desorption of the hydride is about 7 psig to 15 psig while at 38°C the pressure range is approximately 55 to 65 psig.

The rate at which hydrogen gas is liberated from the hydride is very critical during the operation of the fuel cell. The rate is very dependent upon temperature as is shown in Figure 7. In addition, the rate is also intrinsically decreased as the hydride is depleted. The minimum required rate of hydrogen flow to the fuel cell, based upon end of life conditions, would be about .0318 gram moles per minute. This translates into a flow rate of 770 cc per minute at STP. The required decomposition rate expressed in cc H_2 per minute per gram LaNi_5 would be approximately .70 during fuel cell operation. The kinetic data shown in Figure 7 indicated that the required flow probably could be maintained if the hydride was above 0°C . It was realized that if the hydride cooled below that temperature, a point would be reached where the required flow rate could not be sustained.

The canister utilized to contain the hydride material was similar in some respects to pressure vessels used for metal hydrogen secondary batteries. The canister consisted of a seam welded cylindrical inconel 718 outer shell (diameter 2.5 inches, thickness .015 inches) to which flat 3/16 inch stainless steel end plates were welded. Welded to the end plates were three 1/2 inch O.D. stainless steel tubes which would serve as hollow ports within the cylinder to aid in transferring heat to the hydride within the central portion. The gas feed and exit port consisted of a 1/8" tube welded to the top of the cylinder to which a miniature quick connect body was attached. Within the cylinder the 1/8" tube was welded to a 1/4" porous stainless steel filter tube. This tube with an average pore size of .5 microns would prevent fine particles of lanthanum nickel hydride being released with the hydrogen stream into the fuel cell. The hydride particles during succeeding activation and deactivation cycles tend to reduce in size eventually reaching an equilibrium size of about 11 microns." Fracturing of the particles occur because considerable stresses are created in the metal during the 25 percent volume expansion associated with hydriding.

The initial canister design was a four inch high cylinder containing about 15 cubic inches or 246 cc of free volume. This

FIGURE 7 LANTHANUM NICKEL HYDRIDE
DECOMPOSITION KINETICS



D0021

was believed sufficient to hold the required 1100 grams of LaNi_5 and allow for swelling of the alloy during its transformation to LaNi_5H_6 . Previous experience with this size pressure vessel and the electron beam welding techniques utilized for assembly indicated that the burst pressure for the canister would be in the range of 2000 psi. A 750 psi hydrostatic proof test was utilized to verify the pressure vessel design.

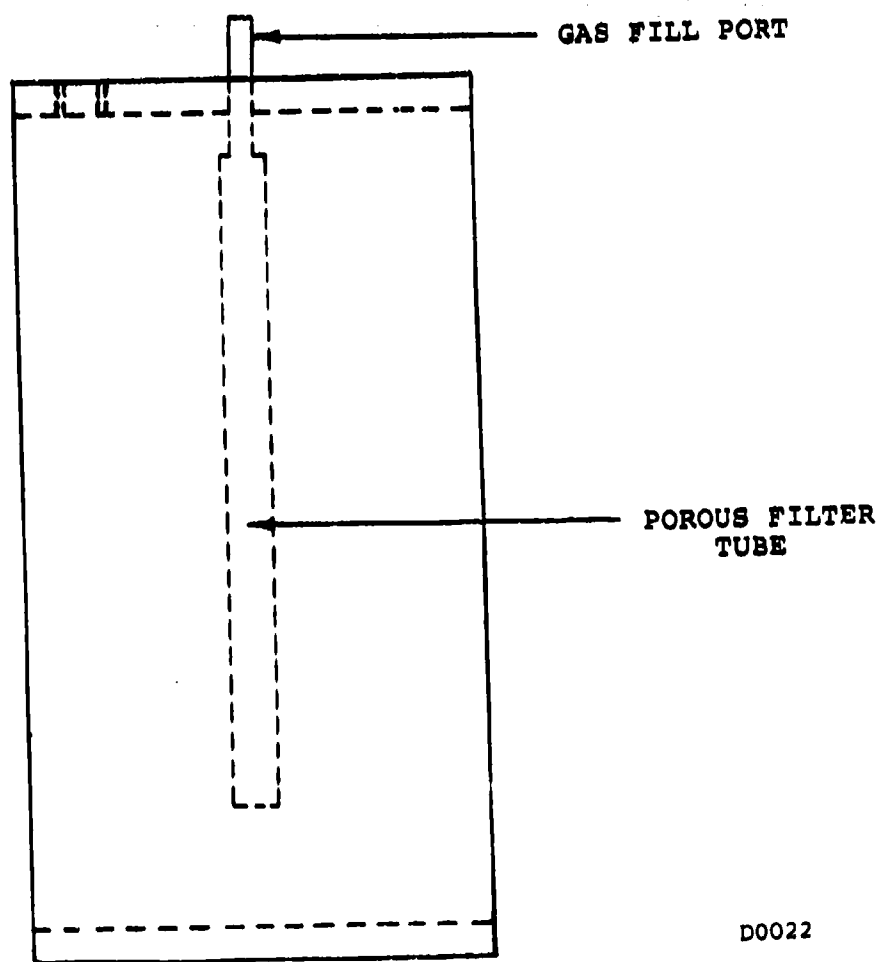
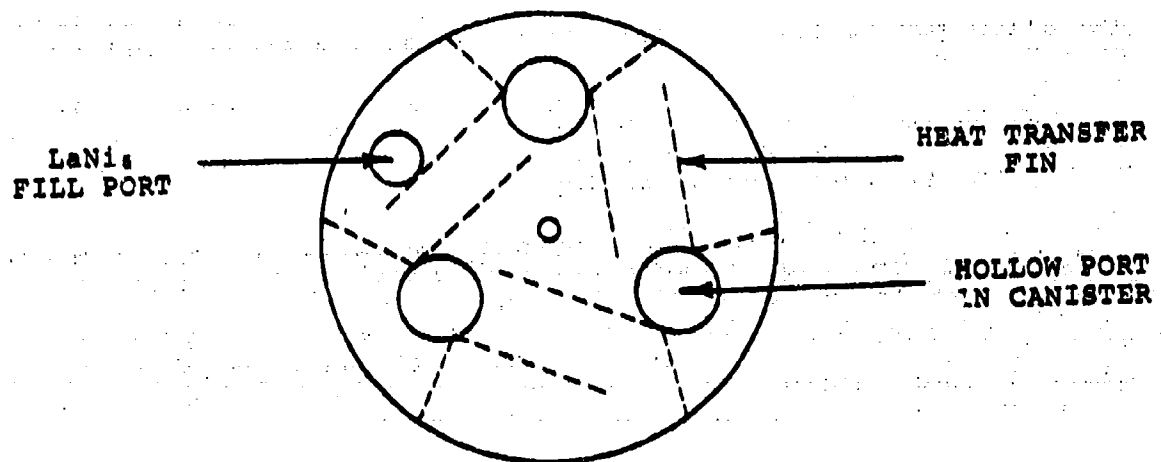
Initial absorption and desorption experiments were conducted with the hydride storage unit prior to total system assembly. The LaNi_5 was added by means of a 1/8 inch pipe threaded hole in the top of the canister. The hole would also serve to hold a pressure gage during initial experiments. The LaNi_5 , as supplied by the Research Chemicals Division of the Nucor Corporation was crushed to an initial particle size of about 1000 microns.

During the initial activation procedure, the canister was submersed in a water bath and connected to a hydrogen cylinder at a maximum pressure of 150 psig for a period of about 20 hours. The initial discharge of hydrogen from the hydride container at the required rate to operate the fuel cell indicated that approximately LaNi_5H_3 had been formed. During the second cycle the previously activated material appeared to reactivate at pressures as low as 80 psig. The second desorption process indicated a conversion equivalent to LaNi_5H_4 had occurred. During an untended portion of the third activation cycle at 150 psig, a failure in the welded seam of the cylinder occurred. Gas pressure was not suspect as the seam originally had been exposed to 750 psig. The most logical explanation for this occurrence was that the canister simply was undersized for that amount of LaNi_5 . The initial design was based upon the density of LaNi_5 (8.29 grams/cc) and assumed a volume expansion of 25 percent during activation. Since LaNi_5H_6 after several activation cycles does not exist as clumps of metal, but rather as fine particles, a more realistic design parameter is probably the bulk density. For LaNi_5H_6 a bulk density of 4.2 grams/cc has been estimated.

A second canister was assembled using similar techniques except the height was increased from four to five inches. The effective volume within the storage vehicle was therefore increased from about 246 cc to 315 cc to compensate for the swelling action of LaNi_5H_6 . In addition, nickel foil was attached to the three ports within the canister to serve as heat transfer fins. Figure 8 shows the final design for the hydride storage unit.

An important supplementary part of the hydride storage unit would be the gas regulating system utilized to control the hydrogen flow to the fuel cell. Typically, the hydride container would be at approximately 80 to 100 psig when installed initially to feed the fuel cell. During operation, the pressure within the canister would undergo a rapid drop to about 30 psig due to consumption of free hydrogen. At that point, the pressure would continue to decline at a much slower rate due to depletion of the hydride and more importantly, the cooling effect associated with the

FIGURE 8 HYDRIDE STORAGE UNIT DESIGN



D0022

release of hydrogen from the hydride. If no heat was added to the hydride source during this period, the canister would cool to below 32°F within 30 minutes and the pressure would drop to less than 3 psig. If heat was added to the canister, a higher pressure level could be sustained.

Since a wide range of pressure levels would exist in the canister during normal operation a series of three miniature regulators were utilized. The first stage regulator would drop the pressure to about 2 to 5 psig depending upon the canister pressure. The second regulator would operate in the range of 10 to 15 inches positive water pressure. Both of these regulators were the non-relieving diaphragm type produced by the Duff-Norton Company. The outlet from the second regulator passes through a latching type solenoid valve contained within the power conditioning unit which allows hydrogen under positive pressure to purge through the fuel cell. If the solenoid valve is closed as occurs during normal operation the hydrogen is passed through a third stage regulator set for an outlet negative pressure of 2 to 10 inches H_2O to feed the fuel cell. Between the second and third regulators, a three way ball valve was placed to shut off the hydrogen flow during temporary shut down periods. This valve open to the atmosphere in the closed position would prevent excessive negative pressures being created within the hydrogen chambers during shutdowns. In addition, a relief valve set to about .7 psi was placed next to the shut off valve to prevent excessive positive pressures being created by possible electrolyte blockages. Figure 9 is a photograph of the hydride container and its regulating system.

3.3 Power Conditioning Unit

The power conditioning unit utilized during this contract has previously been evaluated under Contract No. DAAB07-72-C-0317. The primary function of the unit was to convert the fuel cell power to a regulated constant output of 28 VDC from from 0 to a maximum 2.4 amperes. The circuits necessary for this purpose included a current feedback inverter and a switching regulator. The inverter chops the direct current output of the fuel cell to generate alternating current and subsequently transforms the resulting signal. This in turn is full wave rectified and a 64 volt level is fed to the switching regulator. The regulator provides a constant output voltage and also serves as a constant power device. Therefore, for a fixed load it automatically sets the input power. In conjunction with the regulator, circuitry was also provided for overload conditions. During overload periods such as short circuiting, the output voltage is folded back, thereby keeping the power output essentially constant. This serves to protect the regulator as well as preventing the fuel cell from experiencing severe vacuum conditions. The combination of the inverter, switching regulator and overload protection provided a unit with an approximate efficiency of 80 percent. A schematic of these circuits is presented in Figure 10.

Included within the P.C.U. were additional circuits which

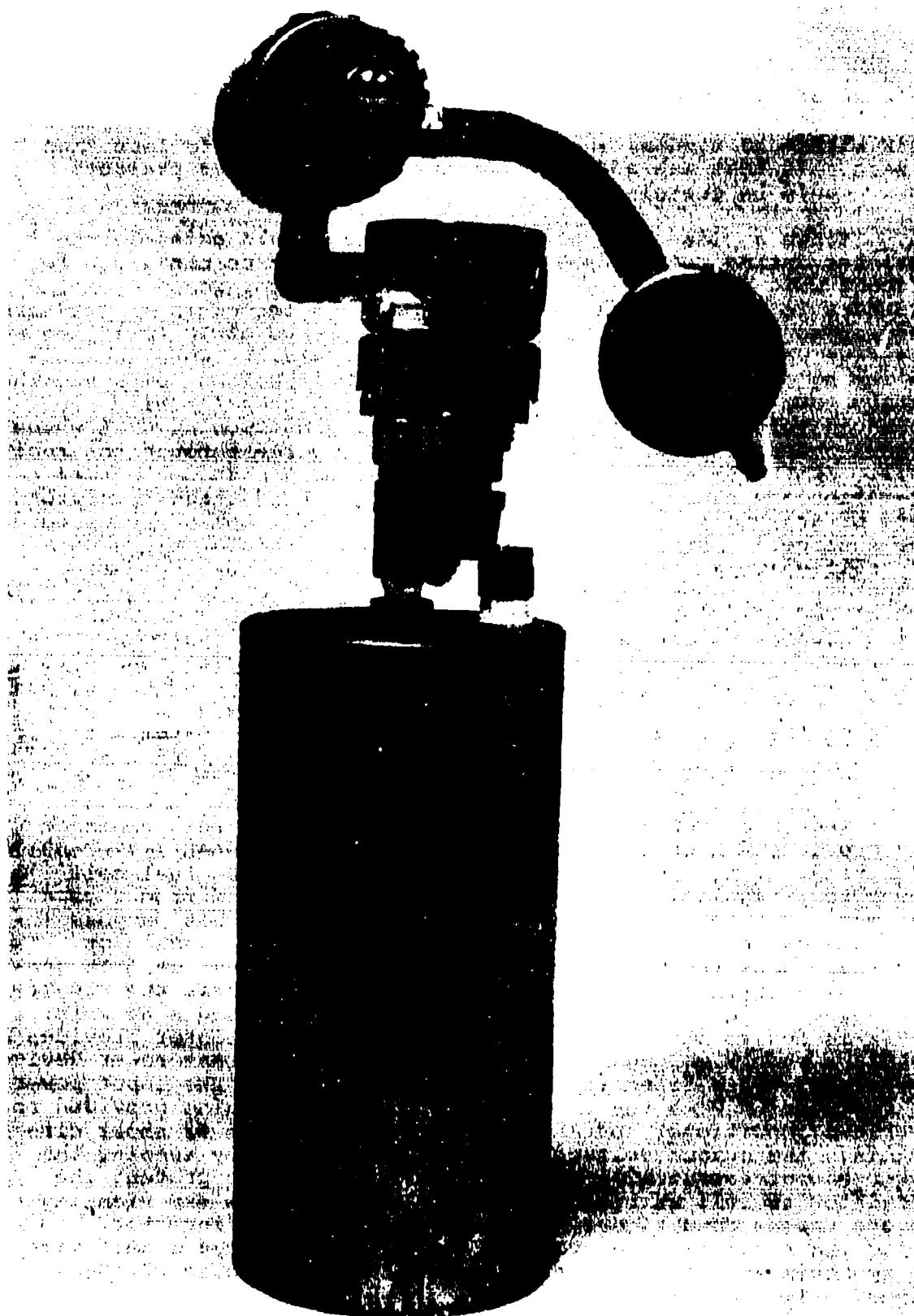
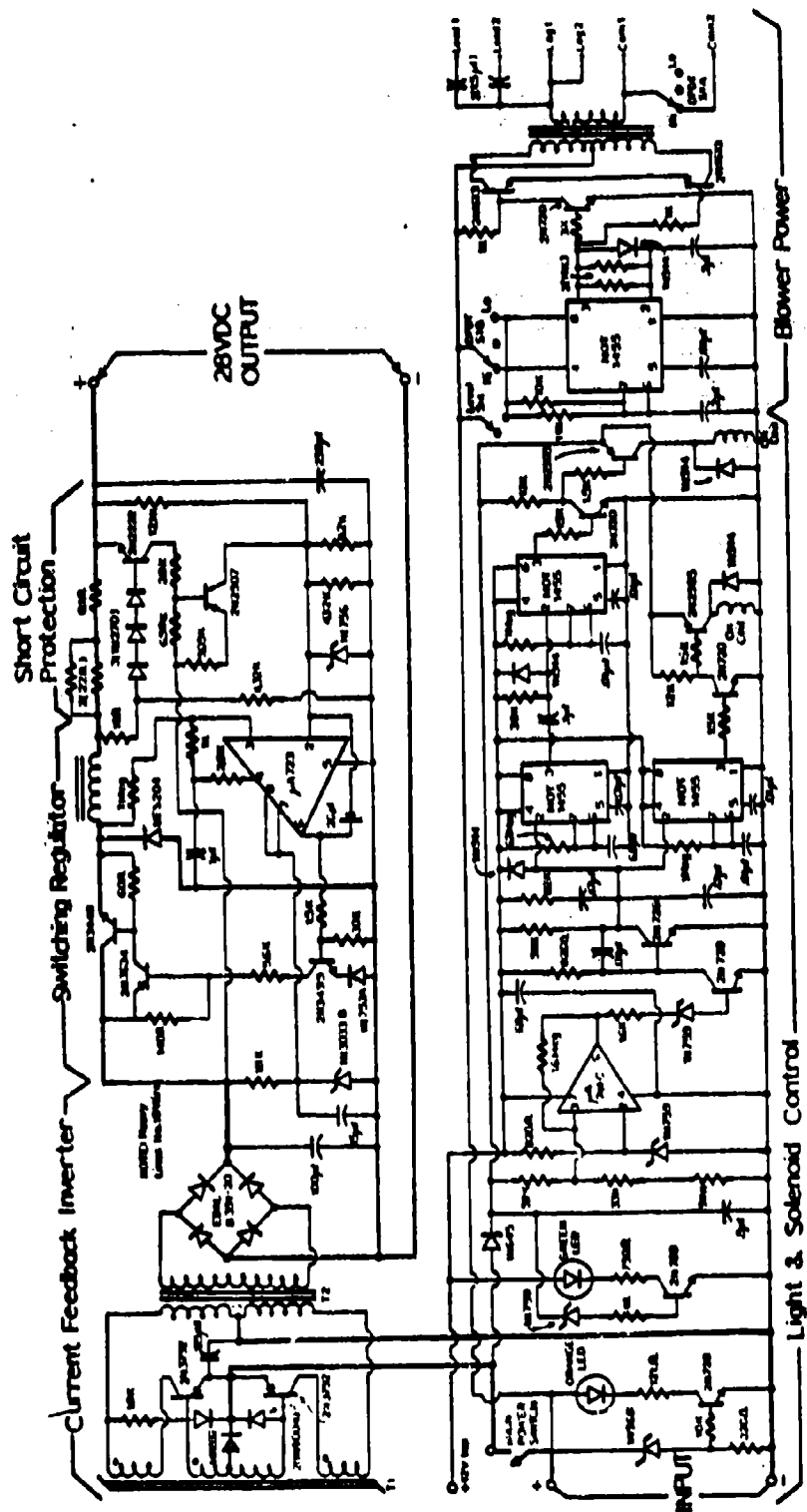


FIGURE 9 HYDRIDE CONTAINER AND REGULATING SYSTEM

FIGURE 10 SCHEMATIC OF POWER CONDITIONING UNIT



aided in automatic unit startup, purge control, and air blower operation. System startup was initiated by turning the control knob to START which opened a ball valve contained with the P.C.U. and allowed hydrogen to purge through the fuel cell. When the open circuit voltage for the fuel cell reached about 20 volts an orange indicator light appeared on the console. The unit was now ready for operation and required switching to the RUN position to interconnect the fuel cell with the power conditioner. At this time, a green indicator light appears if the fuel cell voltage is above 14 volts. Purging of the fuel cell continues for 25 seconds until a time delay circuit closes a latching solenoid valve. This ceases the purging operation and allows the hydrogen to flow through the third stage regulator initiating dead-ended fuel cell operation.

Periodic purging of the fuel cell was necessary during operation because of air entering the hydrogen chambers. If the fuel cell dropped below 17 volts, an automatic purge cycle was activated. The latching solenoid valve was automatically opened and purging was allowed for 40 seconds until a timer terminated the cycle.

The P.C.U. also contained two 3 watt blowers, each capable of supplying 2 CFM of air to the fuel cell. The blowers are necessary to increase air supply during low temperature starts and enhance water removal in moist environments. A manual switch on the console has a low and high setting allowing one or two blower operation. The blower motors were operated by a 400 Hz power oscillator.

The overall efficiency of the power conditioner was reduced to about 73 percent with the addition of the secondary function circuits. A photograph of the complete P.C.U. is shown in Figure 11.

4.0 EXPERIMENTATION

4.1 Activation and Deactivation of Lanthanum nickel

Prior to operation of the hydride container in conjunction with the fuel cell a series of experiments were conducted to evaluate the absorption and desorption characteristics of LaNi_5H_6 utilizing our canister configuration. Efforts during this phase were not directed at studying the activation - deactivation process under controlled temperature and pressure conditions, but to develop a readily reproducible technique to utilize the hydride container within the fuel cell system.

Activation of the 1100 gram sample of LaNi_5 within the 315 cc container was always performed with the canister submersed in about a 20°C water bath. Initial activation was conducted at 80 psig and was gradually increased to 150 psig. The lower pressure level



FIGURE 11 POWER CONDITIONING UNIT

of 80 psig appeared to be a threshold point at which significant hydriding was observed to be occurring. A series of eight activation - deactivation cycles were initially conducted with the hydride container utilizing an activation period of 20 hours. Deactivation of the hydride was performed at a constant flow rate of 770 cc/min. This did present some difficulties if no external heat was applied to the canister as the hydride would cool drastically, thus limiting the desorption process. The most satisfactory technique for evaluating the deactivation procedure was to blow ambient air across the container which maintained the outside temperature at about 16°C.

The initial discharge of hydrogen at the required flow rate resulted in three hours of operation. During the second deactivation cycle, more LaNi_5 was exposed to hydrogen and the operation time increased to 3.3 hours. After six cycles a maximum discharge time of 3.7 hours was obtained. This value indicated that approximately $\text{LaNi}_5\text{H}_{2.5}$ had been formed during activation. Although the hydride conversion was less than expected, the hydride container design was judged to be acceptable for use with fuel cell system. A possible explanation for the reduced capacity of the LaNi_5 could be related to some exposure of the metal to air prior to the initial activation.

4.2 Fuel Cell Testing

Prior to fabrication of the fuel cell stack, a single dual cell element was tested to verify expected fuel cell electrode performance. The unit was tested under simulated system conditions by operating within a heated oven maintained at about 52°C. The cells reached an equilibrium temperature of about 65°C after several hours of continual testing. A total endurance time of 560 hours was compiled with the cells during daily 8 hour operation periods. Figure 12 shows the initial and final average performances for the two cells contained within the unit as operated on hydrogen and air. A current density of 33.3 ASF was generally maintained during the endurance test.

Much of the cell decay was attributed to carbonate formation. Electrolyte replacement at the 200 and 400 hour test intervals did aid in restoring close to initial performance levels. Some irreversible decay was also evident indicating some catalyst and/or electrode deterioration. The dotted line in Figure 12 shows the projected operating line for the cell to maintain a constant power output over its lifetime. Although decay was unavoidable, the results of the single dual cell test tended to indicate that the endurance capability of the fuel cell was sufficient to meet the contract goal.

Two complete 22 cell fuel cell stacks were constructed for use during this program. Both stacks gave nearly identical initial performances operating with bottled hydrogen and ambient air which is shown in Figure 13. The initial stack was utilized mainly as a test vehicle to determine heat transfer characteristics

FIGURE 12 SINGLE CELL PERFORMANCE

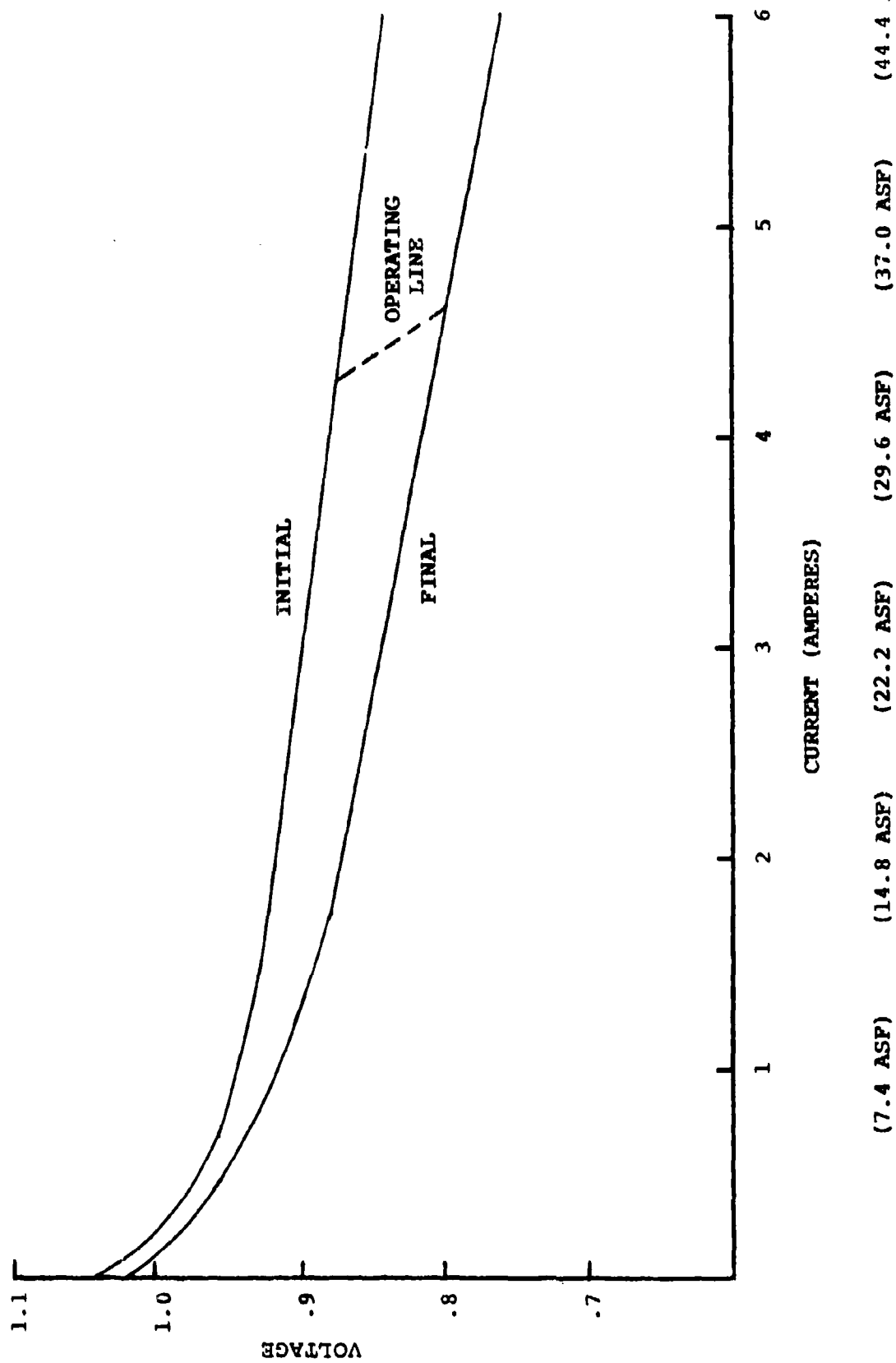
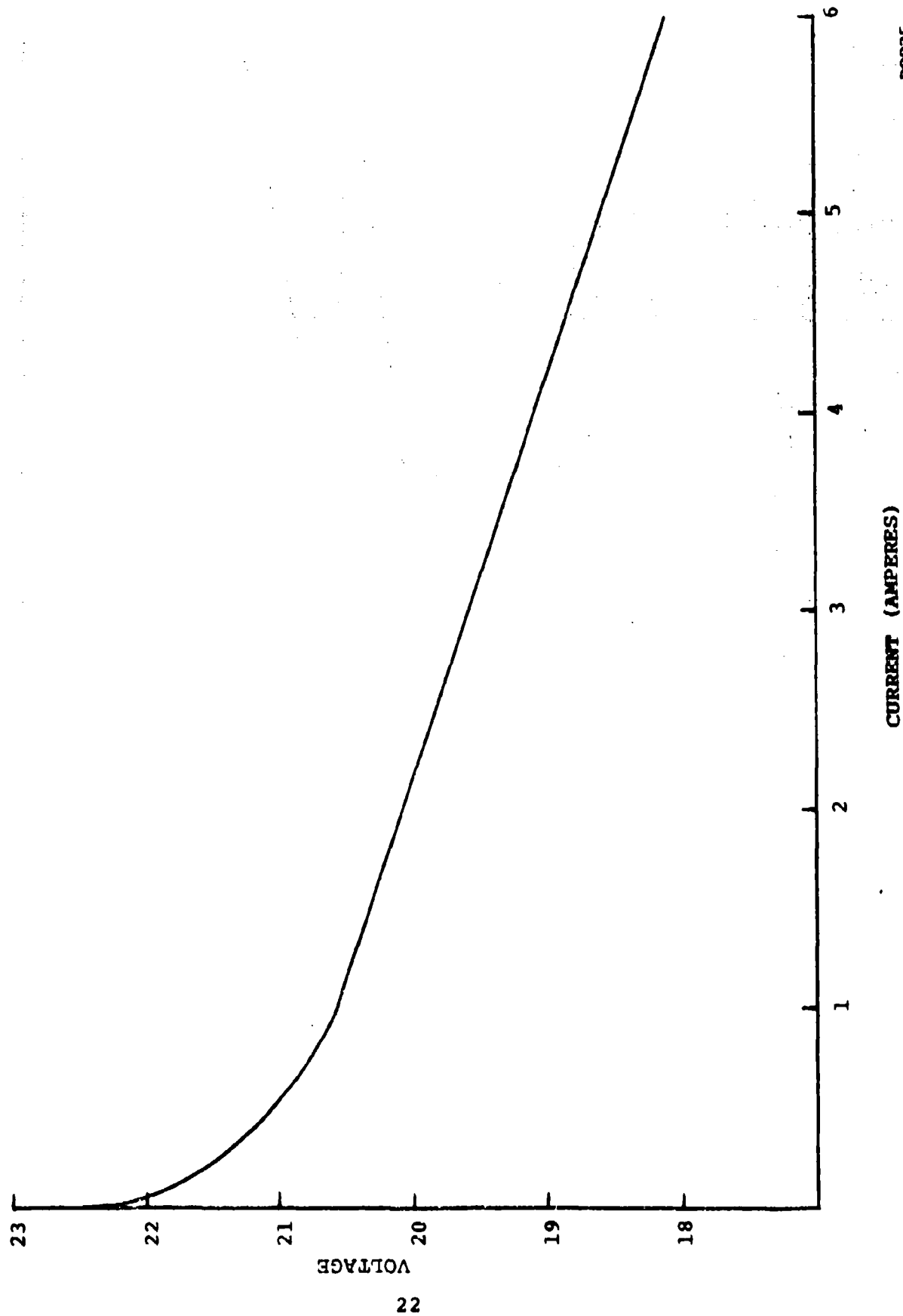


FIGURE 13 STACK PERFORMANCE



between the hydride container and the fuel cell. Several of its cells had a tendency to bubble prematurely at relatively low temperatures for some unknown reason. This did limit operational time before erratic stack behavior coupled with very high cell temperatures was experienced. The combination of high stack temperatures and some long inactive durations when the cells formed carbonates reduced the effective operating lifetime of the initial stack to about 35 hours. Cells within the second stack appeared to resist bubbling to a greater degree and consequently the second stack was utilized within the final deliverable system.

4.3 Fuel Cell - Hydride Container Operation

Initial operation of the fuel cell in conjunction with the hydride container was mainly directed at determining whether the fuel cell could supply enough heat to the hydride to sustain the required flow of hydrogen. The canister was placed in the middle of the split stack in contact only with the outer extremities of the fuel cell polysulfone frame. Initial attempts to operate the fuel cell in this way resulted in drastic cooling of the hydrogen source within thirty minutes thus limiting the hydrogen flow to the cells. It became very evident at this time that poor heat transfer existed between the stacks and the canister. More importantly however, the hydride container was being severely cooled before the fuel cell stacks were even approaching steady state operating temperatures.

An analysis of the heat effects associated with both systems substantiated the fact that the hydride container would be in difficulty after 30 minutes of operation. Although the waste heat rate from the fuel cell was about four times that necessary to sustain the release of hydrogen, the heat capacity of the hydrogen storage unit was only about 11% of that of the fuel cell. As shown in Table I, the net result for the initial startup period was, that the canister would have a tendency to cool at greater than twice the rate that the cells were heating, assuming no effect of the surroundings.

In order to circumvent the cooling problem, a 40 ohm ni-chrome wire heater was added to the system. The heater was placed within one of the canister ports and it operated directly off the output of the fuel cell. The 8 watt output of the heater represented about 50% of the required hydride heat to maintain a constant temperature. This arrangement was sufficient to maintain the necessary hydrogen flow until the fuel cell reached operating temperatures. Generally, the heater was necessary only for about the initial 30 minutes of operation at an ambient of 20°C.

At approximately 75 minutes after startup, another problem did arise. Some portions of the 12 cell stack unit were bubbling, indicating high temperatures were developing. Although sufficient heat was being transferred from the fuel cell to the canister to maintain hydrogen flow, the canister was not being utilized efficiently in preventing excessive stack heating. The hydrogen storage

TABLE I

HEAT EFFECTS DURING INITIAL 30 MINUTES OF OPERATION

A) FUEL CELL

Average Power: 82.3 Watts (18.3 Volts - 4.5 Amps)

Average Efficiency: 56.2%

Waste Heat Rate: 64.1 Watts

Heat Produced: 32.05 Watt-Hours (109 BTU)

Fuel Cell Assumed To Consist Of:

	WEIGHT	SPECIFIC HEAT CAPACITY
1. Polysulfone	5.1 LBS	.3 BTU/LB°F
2. Potassium Hydroxide	2.4 LBS	.7 BTU/LB°F

Total Heat Capacity: 3.21 BTU/°F

Maximum Temperature Rise: 34°F

B) HYDRIDE CONTAINER

Hydrogen Consumption: .923 Gram Moles

Heat Required: 6650 Calories (26.3 BTU)

Required Heat Rate: 15.4 Watts

Hydride Container Assumed To Consist Of:

	WEIGHT	SPECIFIC HEAT CAPACITY
1. Nickel Container	.9 LBS	.107 BTU/LB°F
2. LaNi ₅ H ₆	2.4 LBS	.107 BTU/LB°F

Total Heat Capacity: .353 BTU/°F

Maximum Temperature Drop: 74.5°F

unit in poor contact with a relatively cool portion of the fuel cell appeared to do little in preventing hot spots developing within the central portions of the stacks.

During subsequent testing, use of a copper heat transfer fin thermally linking the upper 3 inch section of the fuel cell with the canister was utilized. The fin was shaped to fit about the periphery of the hydride container as shown in Figure 14. This arrangement required turning the canister upside down with the pressure regulators located underneath. Use of the heat transfer fin increased operation time to 1 hour and 45 minutes under conditions equivalent to a net system output of 60 watts. The limiting factor at this point was the fuel cell stacks which had undergone severe decay, both due to overheating and carbonate formation.

4.4 Complete System Operation

The second fuel cell stack prepared under this program was used exclusively to evaluate the complete system performance and its final packaging configuration. It was believed that the initial stack had suffered considerable deterioration before it was determined how to effectively utilize the hydride storage unit in conjunction with the fuel cell. The initial attempt to operate the complete system did result in premature overheating of end cells next to the power conditioning unit because of direct contact. During subsequent testing, however, permanent bonding with epoxy of the heat transfer fin to the fuel cell overcame some of the slack of component mating and a gap resulted between the fuel cell and P.C.U. This did alleviate the end cell heating problem.

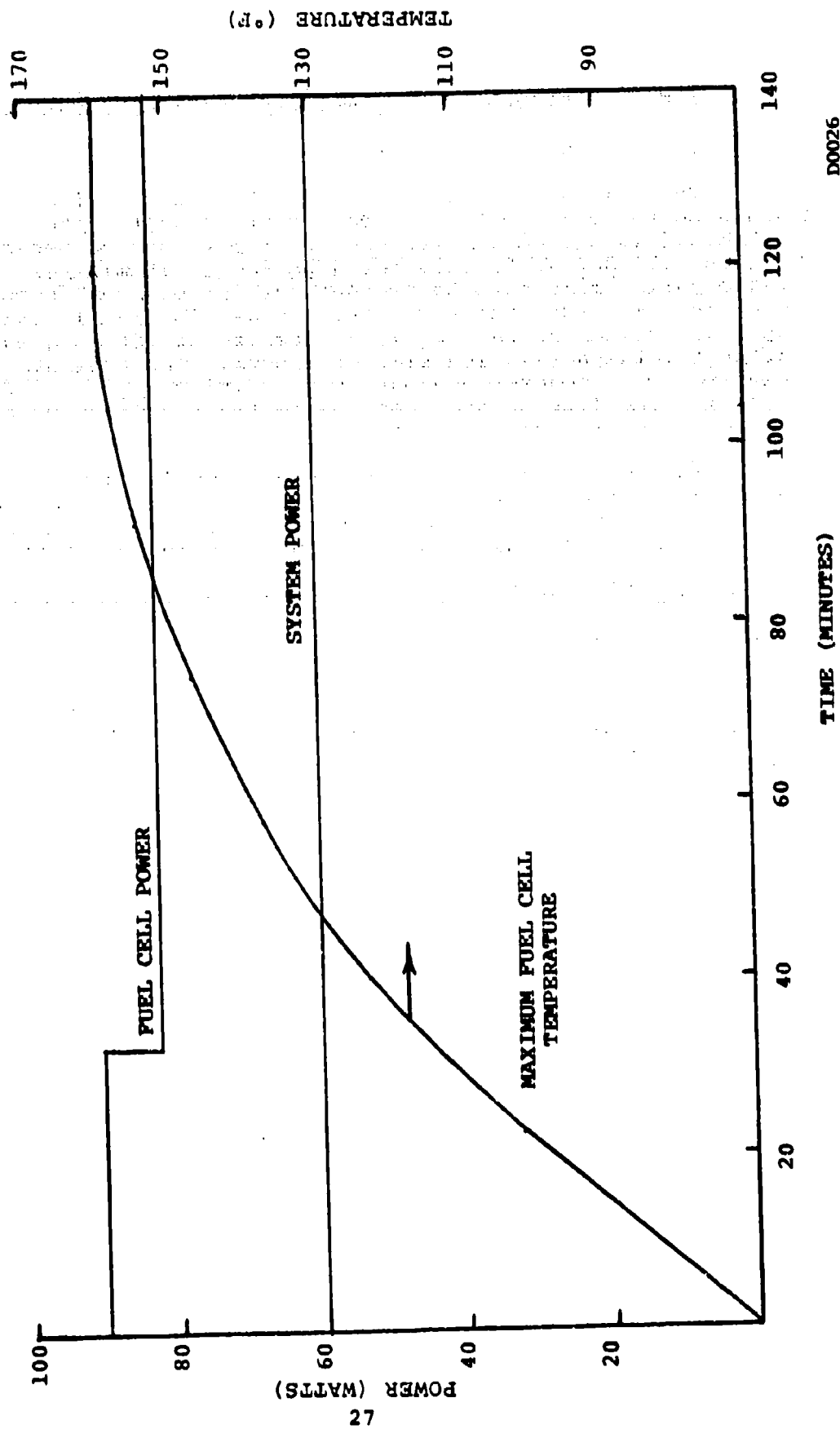
In Figure 15 the system output and the fuel cell output is shown during a 2 hour and 20 minute demonstration. Also shown is the maximum fuel cell temperature as measured in the central portion of the 12 cell units. Although the fuel cell had appeared to reach a steady state equilibrium temperature, the system was being hampered by continually increasing negative pressures being created in the hydrogen chambers of the fuel cell. Since regulator adjustments could not be performed, the high vacuum conditions led to considerable air being sucked into the anode gas chambers. The automatic purge control contained within the P.C.U., at this point was operating erratically and the only technique to prevent possible cell reversal was to momentarily release the load from the system. The hydrogen storage unit at this time did not appear to be thermally limited as sufficient hydrogen was being supplied to the fuel cell. The limitation probably was related to the inherent drop-off in pressure experienced by LaNi_5H_2 as hydrogen is released. It is believed that an improved gas regulating system which could adapt to various canister pressure levels and maintain constant hydrogen chamber vacuum conditions would enable the system to operate successfully for the required time.



FIGURE 14 HEAT TRANSFER FIN ATTACHED TO FUEL CELL

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FIGURE 15 SYSTEM OPERATIONAL CHARACTERISTICS



5.0 SYSTEM OPERATIONAL PROCEDURES AND CHARACTERISTICS

5.1 Operational Procedures

The initial step in operating this 60 watt fuel cell system would be to activate the hydrogen storage unit. The canister was submersed in a room temperature water bath and connected to a hydrogen cylinder at 80 psig for a period of 15 minutes. Care was taken during this step to prevent any air present in the lines from entering the canister. Each succeeding 15 minutes the pressure was raised 20 psig until a pressure of 140 psig was reached after a total activation time of 1 hour. The pressure in the canister was reduced to about 80 psig prior to installation in the system. The loss of hydrogen due to the reduction of pressure was believed to be insignificant.

The hydride container was mounted upside down between the circular portion of the heat transfer fin. This required removal of the case cover. Attachment of the canister to the gas regulating system was performed through the door in the front of the case.

Operation of the system was started by opening the FUEL valve with the operational switch in the START position. This allowed hydrogen to purge through the system. When the orange READY light went on, indicating acceptable open circuit voltages for the cells, the operational switch was placed in the RUN position. This connected the fuel cell output to the power conditioning unit. Shortly thereafter, the HEATER switch was turned on. The heater was generally operated for a period of 30 to 45 minutes depending upon ambient temperatures. The electrolyte return system could also be utilized if required directly after the operational switch had been placed in the RUN mode.

System shutdown could be conducted by switching to the START position and turning the FUEL valve to the off position. This served to not only shut off the fuel supply from the canister, but allowed air to enter the hydrogen chambers. Possible high negative pressures within the hydrogen chambers could therefore be avoided.

5.2 System Characteristics

A photograph of the complete system as delivered, is shown in Figure 16. In Table II the important characteristics of the system are presented. The system did meet the contract guidelines pertaining to output voltages, net power output, automatic start-up, and ability to mate with military batteries. Its weight in excess of 21 pounds was greater than originally anticipated. The demonstrated operational time of 2.33 hours was considerable less than the 4 hour requirement, but could have been increased to 3.7 hours if regulator adjustments during operation were performed. The maximum energy density of the system based upon the weight of the fuel container was 67.2 watt-hrs. per pound, while the demonstrated energy density was 42.4 watt-hrs. per pound. Although the system was not tested at the low and high temperature levels

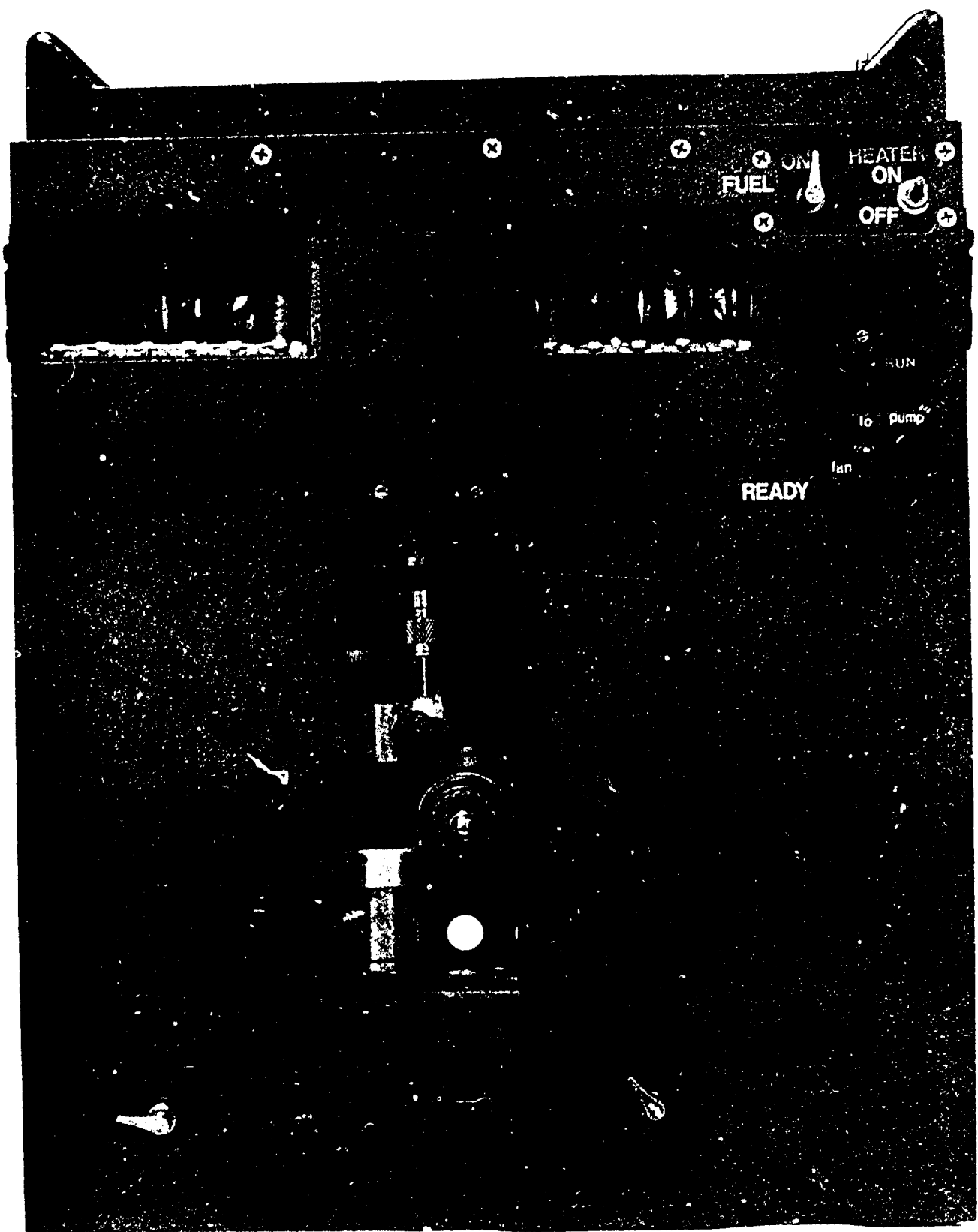


FIGURE 16 COMPLETE 60 WATT FUEL CELL SYSTEM

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TABLE II

SYSTEM CHARACTERISTICS

Voltage	28 VDC
Current, Maximum	2.15 A
Gross Power, Maximum	82-90 W
Net Power, Maximum	60 W
System Volume	.44 cu. ft.
System Weight	
Fuel Cell and Reservoir	5.1 lbs.
Sump Assembly	1.0
KOH Electrolyte	2.4
Hydride Container	.9
La Ni ₃	2.4
Regulating System	.9
Power Conditioning Unit	3.8
Case	3.7
Heat Transfer Fin	.9
Miscellaneous	.5
	<hr/> 21.6 lbs.
Demonstrated Operational Time	2.33 hrs.
Theoretical Operational Time	3.7 hrs.
Maximum Specific Energy per Pound of Canister and Hydride	67.2 Whr/lb.
Demonstrated Specific Energy	42.4 Whr/lb.

its operation at low temperatures probably would have been doubtful due to the kinetic limitations of the hydride. High temperature operation would be doubtful without changes in electrode design to reduce the bubbling tendency. The design of the hydrogen storage unit was sufficient to meet the projected system operational life.

6.0 CONCLUSIONS

The concept of utilizing a reversible metal hydride to supply hydrogen to a 60 watt fuel cell system has been demonstrated at 20°C. After an initial start-up period when a heater is required, the waste heat of the fuel cell is sufficient to sustain the release of hydrogen from the hydride. In addition, if the hotter regions of the fuel cell are thermally linked to the hydride container, a steady state equilibrium temperature will be reached for the cells. The major systems problems identified were the inability to maintain constant negative pressure conditions on the hydrogen feed during operation and the inability for the system to operate in thermal equilibrium over the temperature range of -18°C to 38°C. The cell bubbling problem still exists if the fuel cell reaches temperatures above 75°C which may restrict operation at temperatures slightly above 20°C. For high temperature operation, an improvement in cell performance or a technique for overcoming the bubbling phenomena is required.

7.0 RECOMMENDATIONS

The relatively high ratio of total canister weight to weight of storable hydrogen is about 100 to 1. This ratio probably could be lowered through use of improved alternate hydride materials. A change in hydride container from the present cylindrical configuration to a rectangular design would improve heat transfer characteristics from the fuel cell stack. A specially designed gas regulating system would be required to compensate for all pressure levels existing within the hydrogen storage unit. Changes in the PTFE backing on the electrodes should be attempted in order to stabilize electrode behavior.

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